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The Model of the Rectilinear Propagation of Light and the Study of the Variation of the Size of a Shadow

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The international community of the researchers in science education unanimously agrees on the necessity to take into account, in the elaboration of educational strategies, to specify that all development of educational strategies, the conceptual complexity of the scientific models as well as the various conceptions of the learners. In the present research, we are going to identify the conceptions of future teachers of the primary school with respect to the rectilinear propagation of light as well as the survey of the formation of a shadow and the variation of its size. The analysis of the data of a written questionnaire showed that the majority has erroneous conceptions compared to the scientific conceptions. We are going to see also that one can make evolve their conceptions while developing a didactic strategy centered on the conceptual conflict.

Keywords: training teacher's, primary school, conceptual change, light, qualitative research

Introduction

A review of various researches on the sensitive issue of sciences in elementary schools indicated that children show a fascinating curiosity to understand the material environment with which they interact and, consequently, they develop different conceptions prior to any formal teaching. However, despite of their functional and operational roles, these conceptions appear to conflict with accepted scientific theories (Potari & Spiliotopoulou, 1996, Ravanis, Zacharos, & Vellopoulou, 2010; Russel, Harlen, & Watt, 1989; Selley, 1996; Sharp, 1996; Slone & Bokhurst, 1992).

In order to change these misconceptions, a few studies revealed that it is possible to implement instructional and learning strategies eliciting both children's naive conceptions and scientific conceptions (Canal, 1986; Invernizzi, Marioni, & Sabadini, 1989; Ravanis & Papamichaël, 1995; Ravanis, Koliopoulos, & Boilevin, 2008; Zacharos & Vellopoulou, 2010). Still, we have noticed that, in spite of the evident contribution of these researches, teacher education constitutes a major obstacle to their implementation in the classroom. Indeed, researches conducted among others in England and Australia (Kruger & Palacio, 1992; Kruger, 1990; Smith, 1987) showed some astounding analogies between children and teachers' spontaneous conceptions.

The present paper aimed at, on the one hand, studying the misconceptions of student teachers enrolled in a pre-school and elementary education bachelor's program, in relation to the rectilinear propagation model of light. On the other hand, an approach based on the idea of conceptual conflict was experimented with these

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student teachers in order to facilitate the learning of the model.

Thus, we managed to bring a significant proportion of student teachers to realize the conceptual path necessary to assimilate the rectilinear propagation model of light, the steps of which shall be introduced here.

Methodology and Population

We proceeded to elicit the misconceptions of 119 student teachers and teachers in service, with classical methods, such as a paper-pencil questionnaire. The majority of student participants are practicing teachers holding undergraduate degrees (special needs education, physical education, arts, psychology, dance or music teaching and French as a second language teaching) and whose average age is 30 years old. They are presently studying for a second bachelor degree in preschool and elementary teaching. In order to personalize the information and ensure their anonymity, the students have been identified as S*n* (the *n*th student).

Paper-Pencil Questionnaire: Development and Analysis

We have retained four simple questions as shown in Appendix A to identify students' misconceptions about shadow and light. It should be noted that these questions were based on the works done worldwide on pupils' misconceptions about light (Guesne, Tiberghien, & Delacote, 1978; Kaminski, 1980; Ravanis & Papamichaël, 1995; Tiberghien, Delacote, Ghiglione, & Matalon 1980). Herewith are the targeted objectives put forth by each of the questions and their analysis?

Analysis of the first question. The objective was to predict, in situations A and B (see Appendix A), that only a small portion of the wall will be illuminated, in conformity with the rectilinear propagation model of light, the one which goes from the bulb and through the hole in the screen, travelling in a straight line. However, in the third situation, the wall does not receive any light because the light going through the first screen is intercepted by the second screen. The following diagram illustrates these situations (see Figure 1).

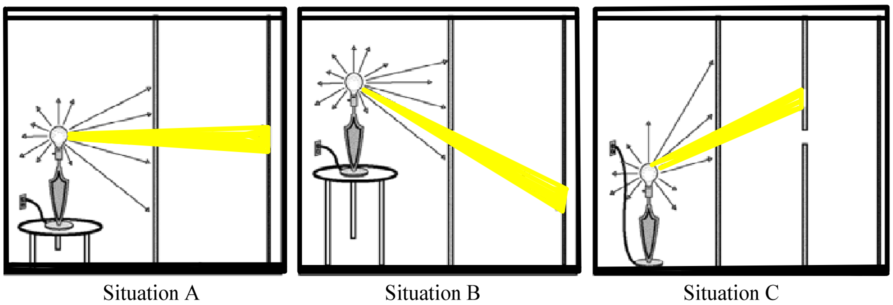

Figure 1. Light beam—Opaque object (the wall).

The analysis of situation C clearly outlines teachers' general conceptions about the rectilinear propagation of light. Furthermore, situations A and B help us to understand the different steps in their reasoning. Thus, the analysis of data has permitted us to observe four categories of answers for situation C.

Category 1 (12%): The wall in situation C will be struck by light. Light travels in a straight line and can change direction in the same propagation environment. It is a misconception illustrated by the following sample of answer (see Figure 2).

Category 2 (49%): The wall in situation C will be struck by light. The light beam travelling through the hole in the first screen is large enough and it goes through the opening in the second screen. It is an erroneous conception illustrated by the following sample of answer (see Figure 3).

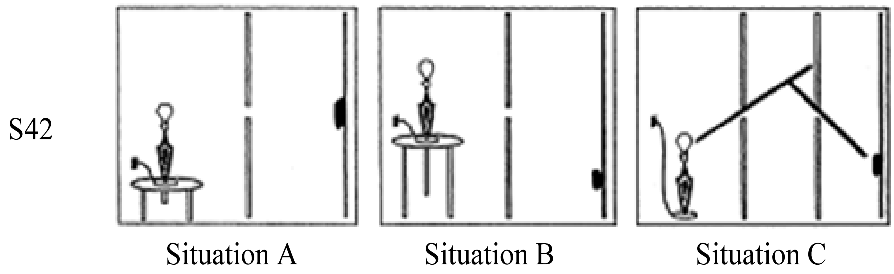

Figure 2. Change of direction of the luminous ray in a same area (air).

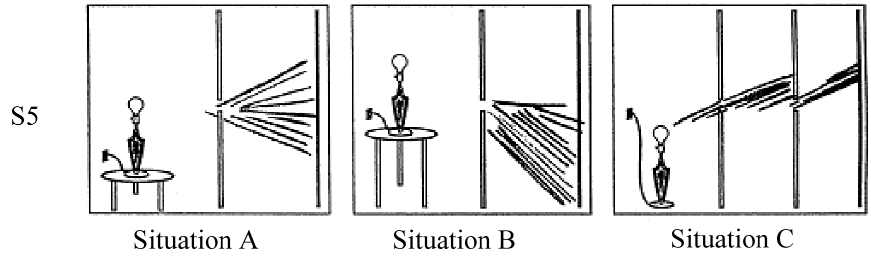

Figure 3. The wall is illuminated (situation C).

Category 3 (27%): The wall in situation C will not be struck by light. It is an accurate conception illustrated by the following sample of answers (see Figure 4).

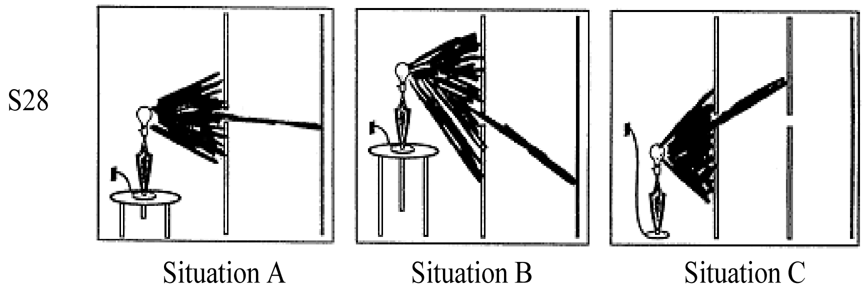

Figure 4. The wall (situation C) is not illuminated.

Category 4 (12%): Incomprehensible or incomplete answers (see Figure 5).

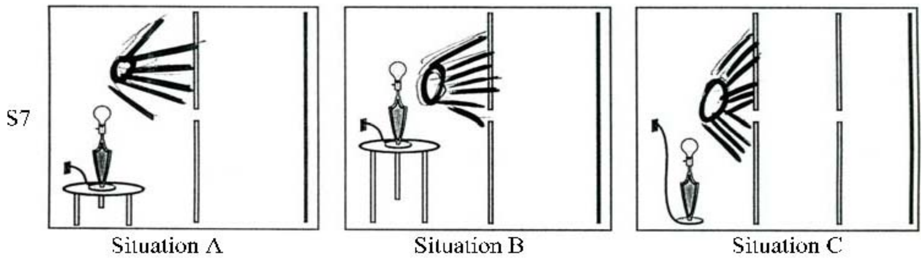

Figure 5. Incomprehensible.

Analysis of the second question. We want to verify if the students will implicitly or explicitly refer to the rectilinear propagation model of light to determine the child's shadow as illustrated in Figure 6.

We have divided the answers into four categories illustrated bellow.

Category 1 (10%): The part of the shadow between the child and the lamp will be visible, either in situations A or B. It is a misconception illustrated by the following sample of answer (see Figure 7).

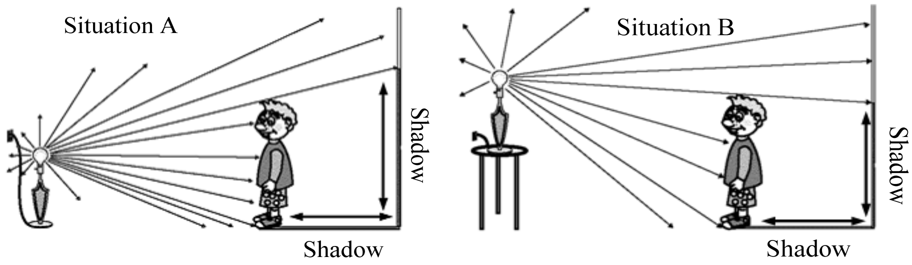

Figure 6. Application of the rectilinear model of light.

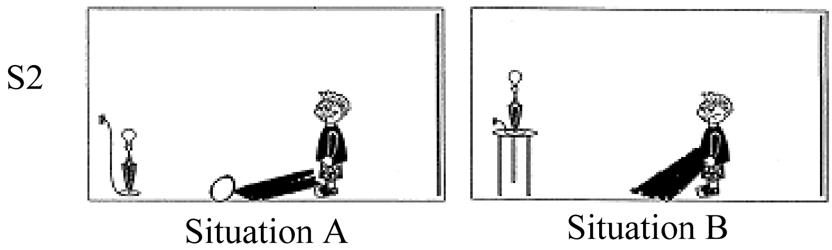

Figure 7. Formation of the shadow between the lamp and the object.

Category 2 (40%): The child's shadow will be visible either on the wall or the floor, but not on both at the same time. No reference to the rectilinear propagation model of light is seen here. It is a misconception illustrated by the following sample of answer (see Figure 8).

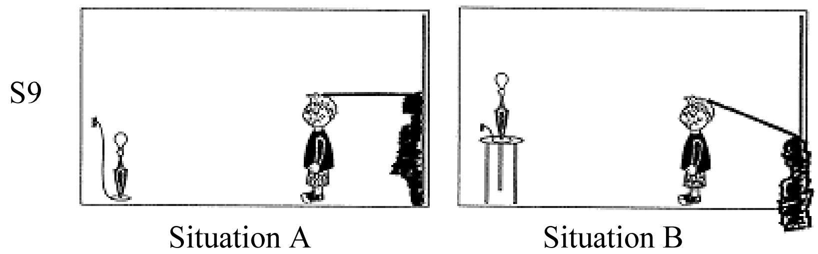

Figure 8. Shadow on the wall or the floor.

Category 3 (18%): A reference to the rectilinear propagation model of light is seen here. It is an accurate conception illustrated by the following sample of answer (see Figure 9).

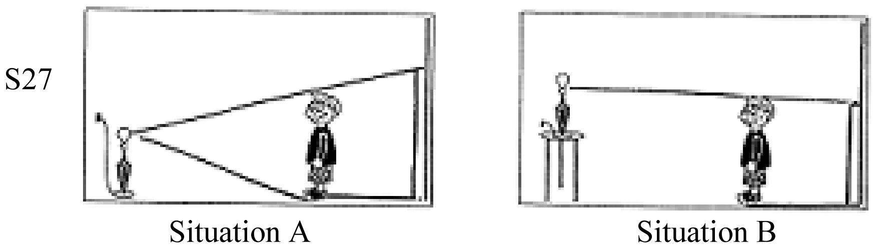

Figure 9. Shadow on the wall and floor.

Category 4 (32%): Incomprehensible or incomplete answers (see Figure 10).

Analysis of the third question. We asked the students to predict how the size of an object's shadow will be modified according to the distance between the object and the source, and that between the object and the screen. The rectilinear propagation model of light shows that the further an object is from a light source, the

smaller its shadow and vice versa. We identified three categories of answers:

S5

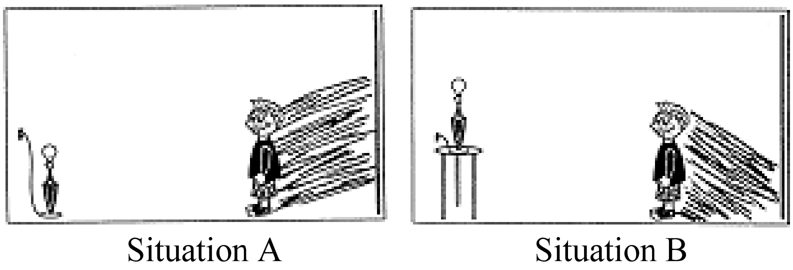

Figure 10. Incomprehensible.

Category 1 (34%): The further an object from a light source, the larger its shadow and vice versa. It is a misconception illustrated by the following sample of answer:

> Bigger, because it always grows and then, the object will be closer to the screen and bigger, therefore, larger for spectators. Smaller, longer distance to travel makes it lose volume. (S11)
>
> Smaller than the initial shadow because the dragon being farther from the light, the angle of reflexion will be larger.
>
> Smaller, because the angle of reflexion will be smaller. (S28)
>
> Larger, more blurred. The closer the object to the screen, the smaller it is. The further the object from the screen, the larger it becomes.
>
> Smaller, since it will be an object with little reflexion. The object will be of standard size. (S68)

Category 2 (33%): Provides a correct answer, that is, the further an object from a light source, the smaller its shadow and vice versa. Here are some sampled answers:

> The shadow will be smaller. In getting closer to the screen, the dragon hides less space from the light reflected behind the screen.
>
> The shadow will be bigger. I think that in getting closer to the light source, the dragon block more space and therefore makes a bigger shadow. (S7)
>
> The shadow will be smaller than the initial shadow because the source of light will be further away. The object will generate a smaller obstacle in front the source of light.
>
> The shadow will be bigger because the object will be closer to the light and will be a bigger obstacle to the source of light. (S23)
>
> Smaller, because the angle of projection of light will be larger. Furthermore, the light can lighten more without its effect being blocked.
>
> Larger because the dragon will block more light, therefore, the angle of light projection is smaller. (S32)

Category 3 (33%): Provides a correct answer without explanation.

Analysis of the fourth question. This question aimed at predicting how the size of an object shadows would be modified if a 40 W bulb was replaced by a more intense bulb, a 100 W, for example. The analysis of data sampled by the questionnaire revealed six categories of answers as follows:

Category 1 (25%): The size of the shadow will be smaller with a more powerful bulb. It is a misconception illustrated by the following sample of answer:

> The first is correct because the more powerful a bulb, the less shadow one can see. (S1)
>
> Because there is lighter brightening the box, therefore, the part in the shadow is smaller. (S72)
>
> The first box because the beams are brighter and "go around" the box more efficiently. (S78)

Category 2 (16%): The size of the shadow will be larger when the bulb is more powerful. It is a misconception illustrated by the following sample of answers:

> The source of light is more powerful, so the shadow is larger. (S4)
>
> The more powerful a light is, the larger the field of the shadow. (S8)
>
> The light is in the corner of the box, so it reflects more on the box whose shadow will be larger. (S10)
>
> Because light is more powerful, more scattered, so the box is more lightens. (S15)
>
> It is through a more powerful 100 W light bulb that shadow gets larger. (S64)
>
> The more powerful the light, the more it is hidden by an object and the more its shadow is darker and larger. (S76)
>
> The beams of light go farther because the bulb is more powerful. (S84)

Thus, 41% of students interviewed maintained that the size of shadow would be different according to a bulb of a different intensity. It should be noted that a similar research conducted by Tiberghien et al. (1980) with approximately 100 children aged between nine and 12 showed that 60% of them had the same misconception.

Category 3 (34%): The size of the shadow will not change, since the distance between the source and the object remains the same and its size did not vary. It is an accurate conception illustrated by the following sample of answers:

> To me, the shadow will be identical since the lamps remain at the same place and the cube is the same one. The light's intensity is different, but its angle remains the same and, moreover, it is the object which gives its own shadow. My own shadow is not larger because the day is brighter. (S16)
>
> The second image: The quantity of W does not disturb the shadow since the light is still at the same place. (S19)
>
> I think that intensity does not change anything. The shadow is generated according to the spot where the light source emanates and how the object is placed. (S24)
>
> The second image is right. If the light's angle in relation to the angle remains unchanged, then the shadow will not be modified. (S41)
>
> The bulb remains at the same distance from the block and the block hides the same space of light. (S105)

Category 4 (16%): The size of the shadow will not change, because the intensity of the bulb does not affect it. It is a correct answer but without further elaborations. Here are some examples:

> The strength of the bulb does not change anything. (S46)

> The second image because the shadow is the same. The strength of the bulb does not change the shadow on the ground, but we can see it more clearly if the light is stronger. (S92)
>
> The second because I do not think the intensity of light has an effect on the dimension of the shadow made by the box. The light field generated by the lamp is the same except that the shadow will be darker. (S104)

Category 5 (7%): The size of the shadow will not change. Provided explanations are either erroneous or incomplete.

> It is the second drawing. To me, the shadow's size will remain the same. It is the intensity of the light in the room which will change. (S26)
>
> Same thing. Because it is the box that generates the shadow but not the strength of the light. (S28)
>
> The shadow will be the same but more visible. (S29)
>
> (Second drawing) explanation: the intensity of light does not have any impact. The object is opaque and cannot filter any light. (S36)

Category 6 (2%): No answer.

The results from these four questions points to the fact that only a small proportion of the interviewed subjects apply the principle of light's rectilinear propagation to identify an area of shadow or a lit area in a given situation.

These exploratory findings bear out the necessity to train future elementary teachers, knowing that they hold misconceptions in comparison with the accepted scientific viewpoints. Being aware of these ideas is an essential condition to the development of efficient teaching strategies. To this purpose, we have designed a few simple didactic sequences in accordance with the model of light's rectilinear propagation and which results are promising.

Summary of the Results of the Paper Questionnaire

The most widespread conceptions are as follows:

(1) Light does not necessarily propagate in a straight line;

(2) Light propagates in a straight line, but only in the horizontal direction;

(3) Light is reflected when meeting an obstacle on its path;

(4) Light changes direction in the same area of propagation;

(5) The size of an object's shadow varies with the intensity of the bulb;

(6) The further an object from a lighting source, the larger its shadow.

Those of the scientists' regarding the light phenomena are as follows:

(1) Light is generated by sources of light and is made up of corpuscles moving in a straight line;

(2) The size of the shadow of an object depends only on the relative distances among the source, the object and the observation screen.

Destabilization Didactic Procedures of the Students' System of Spontaneous Conceptions: Conceptual Conflict

An approach centered on the idea of conceptual conflict was used to facilitate the learning of the model of light's rectilinear propagation. Thus, during three sessions of three hours each, we managed to get a majority of

subjects to solve problems involving the understanding of the aforementioned model. They went along the indispensable conceptual path to build the model in the four steps.

The First Step: Experiments on Light

To disrupt the misconceptions outlined in the previous phase, we invited them to achieve the following experiments.

The light propagation in the space. We invited them to realize four experiments and asked them to find a characteristic of the light explaining their observations. The observation results are summarized in Figure 11 showing the light's propagation in a straight line and in all directions.

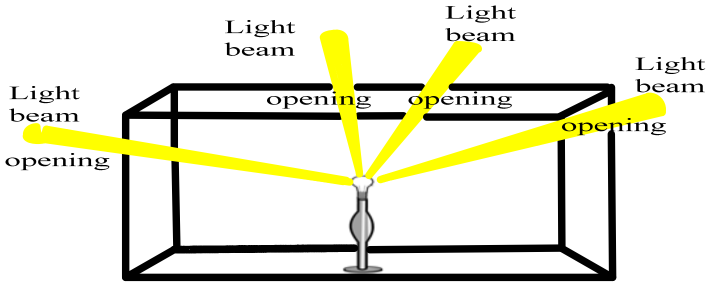

Figure 11. Light propagation in the space.

The rectilinear propagation model of light. It should be noted that the students experienced some difficulties to observe, for example, one beam. For that, we suggested that they do an experiment as shown in Figure 12, to better understand what is meant by "light beam". The realization of this experiment involves particular conditions of observations. It is important to notice that the observed luminous ray does not have a physical existence. It is about a model (construction of the mind based on the experience in this particular case) that has its limits of applicability and that cannot explain all phenomena joined to light as the formation of colors. This model acts as basis to the geometric optics where all beam of light is represented by a set of luminous rays.

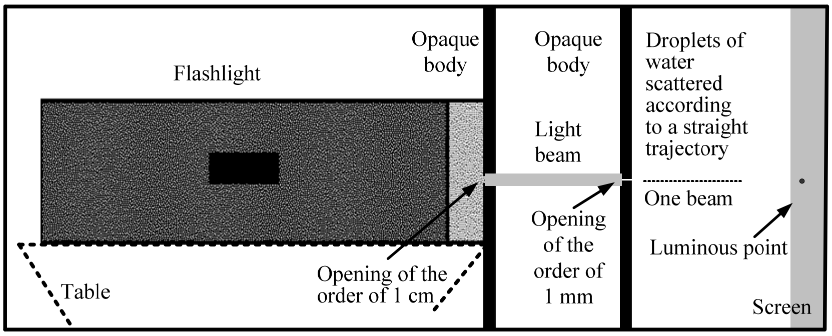

Figure 12. Rectilinear model.

The study of the size of the shadow. Secondly, we asked them, on the one hand, to write down any observations when moving an object in front of a bulb in a fixed position. The point was to describe the shape and the dimensions of the object's shadow. The students had to compile the size of the character's shade as illustrated in Figure 13 while making vary the distance between the lamp and the character. Thus, they will observe that the size of its shade depends on the relative distances among the luminous source, the character and the screen.

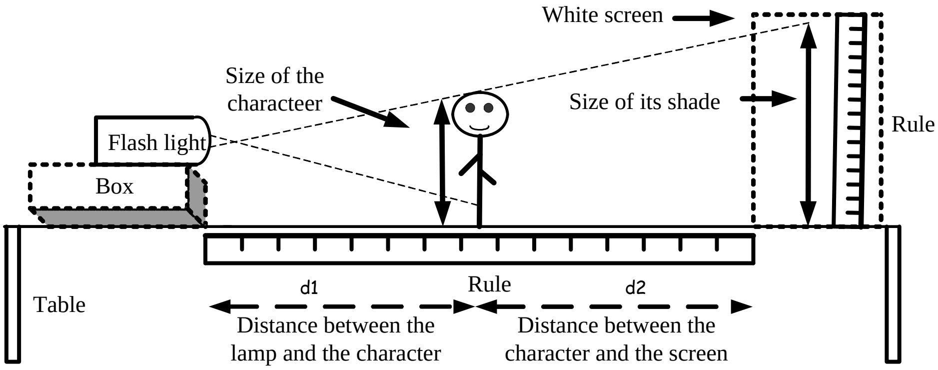

Figure 13. The size of the shadow.

Then, the students had to solve the following problem: If one places the character at a new distance from the lamp, will one know the size of its shadow, without actually measuring it.

Finally, we required them to do the same experiment, this time modifying the light's intensity. This experience has for the object to show that the intensity of light does not affect the dimension of the shade (see Question 4 in Appendix A).

The situations presented to the students lead to a profusion of interpretations and helped to grasp partially one fundamental property of light and some elements of answer to the initial questionnaire. Indeed, the proposed situations outline the students' explanatory system and those of the scientists' and consequently, promote an interaction that is an active observation.

Clearly, it is an understanding of the difference between their predictions and the information found during their interactions with the situations given to them. Such an approach encourages a conceptual conflict which will be resolved with significant learning, through the process of assimilation and accommodation (Posner, Strike, Hewson, & Gertzog, 1982; Stepans, 2008).

The Second Step: Interpretations of Experiments

We first interpreted the experiments in the classroom by holding a discussion among the students. Thus, we highlighted the difficulties encountered during the experiments, especially those regarding the observation of the rectilinear propagation of light. Also, we specified the limits of applicability of the rectilinear propagation model of light, especially in relation to the nature of the context of propagation and the conditions of observation of a light beam.

The Third Step: Some Further Enhancing Learning Activities

We proposed three enhancing learning activities on the following three themes: "Let us play a detective", "The model and the shadow" and "The shadow and the time of day". The first two themes involve predicting, for example, an object's position in a room, knowing that of its shadow and the lighting source. The third theme aimed at raising the issue of the orientation of a lighting source in order to bring students to achieve that the size of an object lit up by the sun increases the closer it is to the horizon. These materials helped them to consolidate their conceptions regarding the rectilinear propagation of light. It also allowed certain awareness for the issue of teaching the concept of light to pupils, because we asked them to set up the lesson plans meant to help them take an active part in the solving of the problems mentioned. Concerning this, it is important to note that the proposed situations did not always have a detailed step-by-step procedure, so as to avoid students

to resort to a mechanical approach.

The Fourth Step: A Few Problems on Light After Teaching

Three weeks later, we had the students answer a written questionnaire (see Appendix B), the results of which show that they have understood the rectilinear propagation of light. Indeed, regarding the first part of the first question, 96% of the interviewed subjects gave a correct answer, that is, looking at the bulb through the straight tube, some light will be seen. As for the second part, 86% said that no light will be seen if the tube is bent. Also, 60% of the subjects identified correctly and precisely the sizes of the girls' shadows (see Question 2 in Appendix B) as illustrated bellow (see Figure 14).

S28

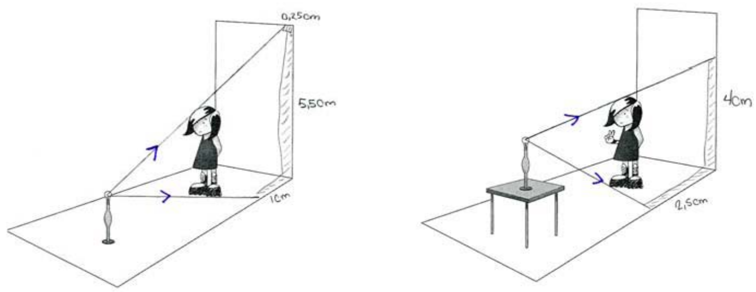

Figure 14. The size of the shadow.

Relatively to the Question 3 in Appendix B, 80% of the students applied the light rectilinear propagation model efficiently to determine the moon's shadow when lit by the sun as illustrated bellow (see Figure 15).

S8

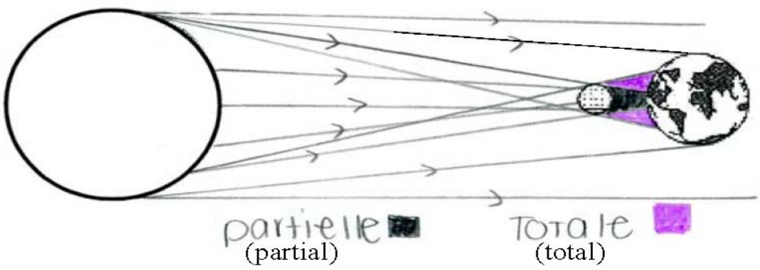

Figure 15. Moon's shadow.

A survey conveyed in Greece by Ravanis and Papamichaël (1995) proved that children at the end of the first cycle of elementary education have gained a sound understanding of the rectilinear propagation model of light. Finely, with regard to the size of the source compared to the one of the object to avoid the formation of darkness, for 20% the size must be bigger, for 22% the size must be identical and for 58% the size must be smaller.

(S40) More the luminous source is small, more the luminous rays seem to go in the same direction. Therefore, as illuminating the object zones it of darkness is very small or even inexistent (see Figure 16).

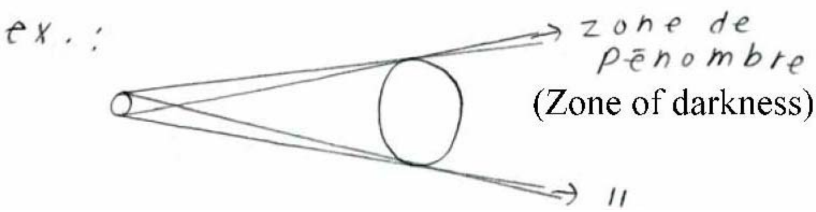

Figure 16. The size of the source relatively to the size of the object.

Thus, 44% advanced a false answer what shows that the question of the size of the source relatively to the one of the object puts some difficulties.

Conclusions

We can question the reasons that explain that a principle as seemingly simple as the rectilinear propagation model of light is not readily accessible and why a majority of adults still retain misconceptions from their childhood. The fact that lighting is often generated by large sources generating blurred shadows probably contributes to the formation of these myths. In daily life, simple situations, exampling the rectilinear propagation of light, are rarely found. Scientists often use complex apparatus from a technical viewpoint, a primary purpose of which is often to set up simple situations enabling them to isolate the phenomenon they wish to observe.

In our survey, the chosen approach consisted precisely in exposing teachers to situations as simple as possible, but without resorting to complex environments susceptible to take us away from everyday situations. This approach, which appears to be promising, would be applicable to other contexts where simple principles are masked by the apparent complexity of situations.

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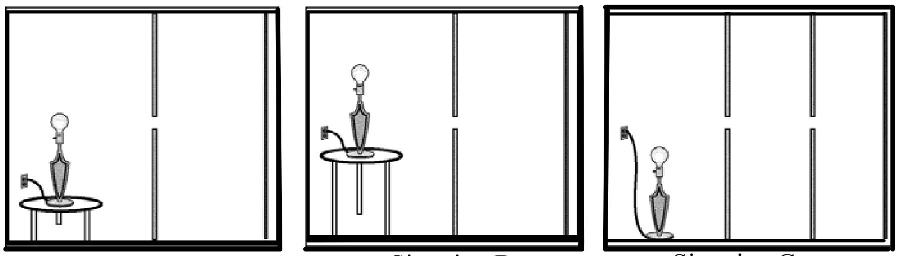
Appendix A: Questionnaire on Light Prior to Formal Teaching

Question 1: Rectilinear propagation of light

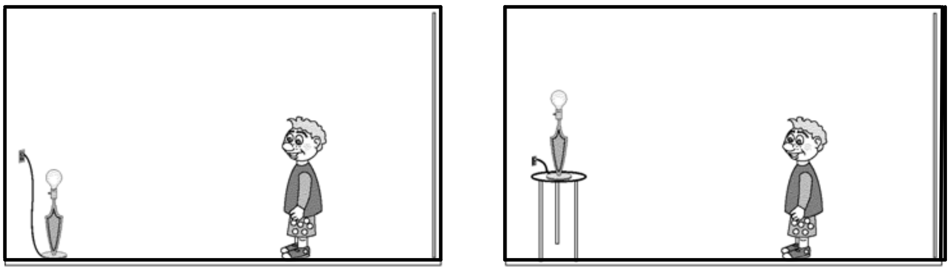
On the picture below in situation A, a lamp without lampshade is lying in front of a black (or any other color) screen in which a hole was made. In situation B, the lamp is placed in a different way, and in situation C, there are two screens. For each situation, draw precisely on the wall, the spot which will be lit up when the lamp will be turned on.



Situation A Situation B Situation C

Question 2: Identification of the size of a shadow

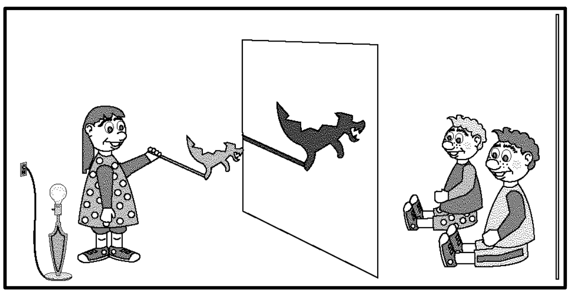
On both drawings below, a lamp is placed in front of a child standing opposite a wall. Draw precisely on the wall and on the ground, the spot where a shadow will be seen.



Situation A Situation B

Question 3: Variation of the size of a shadow.

The drawing below shows children watching a shadow show. The puppeteer is positioned between a lamp and a translucid screen. The children watch the spectacle on the other side of the screen.



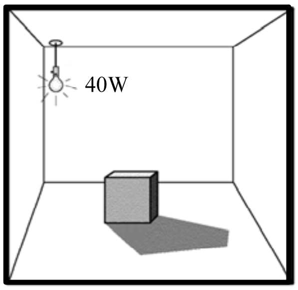
(1). If the puppeteer takes the dragon away from the lighting source, will the shadow be smaller, the same size or larger than

the initial shadow?

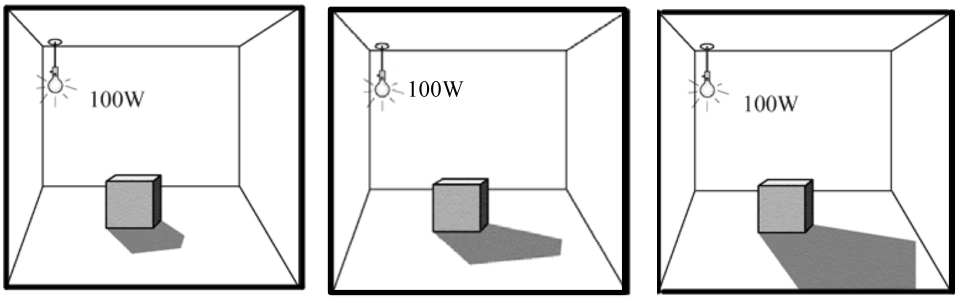
(2). From the initial situation in the drawing, if the puppeteer brings the dragon closer to the light source, will the shadow be smaller, the same size or larger than the initial shadow?

Question 4: Intensity of a light source and shadow.

The drawing opposite shows the shadow of a box lying on the ground and lit up by a low intensity bulb (40 W).



It is replaced with another one, same size but brighter (100 W bulb). Comparing with the previous drawing, choose which one shows the right size of shadow among the three. Explain your answer.

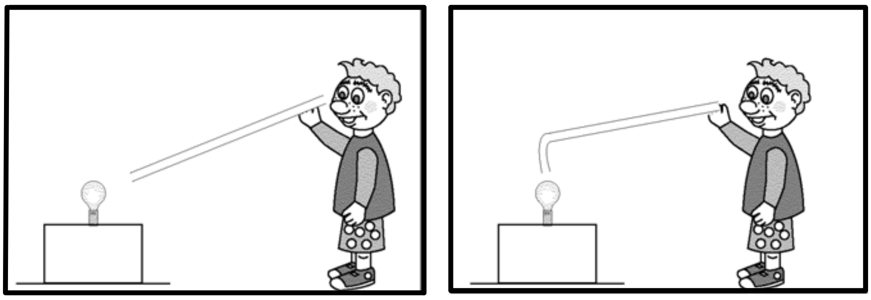


Appendix B: Questionnaire on Light After Formal Teaching

Question 1

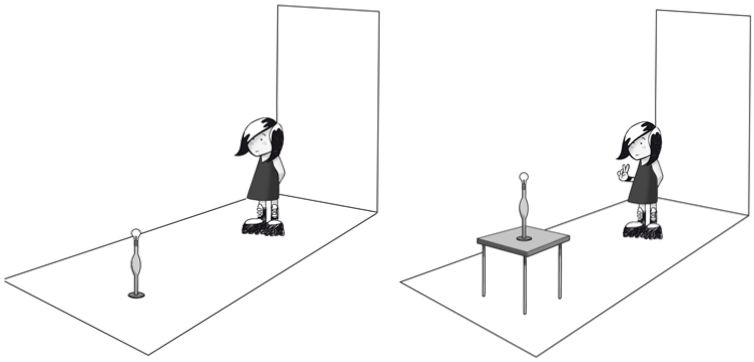
According to the left schema, what will the child observe when looking at the lighted bulb through the straight plastic tube with a black interior? Justify your answer.

If we replace the straight tube by a curved one, as illustrated by the right schema, what will the child observe in this situation? Justify your answer.



Question 2

Draw the places where there will be the little girl's shades and measures in centimeters (cm) her sizes.



Question 3

Draw with precision the shadow of the moon when it is lit by the sun as illustrated by the diagram below. Record all your observations.

Question 4

The following diagram illustrates the shade of a small girl. While justifying your answer, draw the sun to the suitable position that will permit the formation of this shade.

Question 5

To avoid the formation of darkness, the size of the luminous source in relation to the size of the object must be:

☐ Bigger ☐ Identical ☐ Smaller

Justify your choice.